EXPERIMENTAL INVESTIGATION OF THE EFFECT OF DRYING AIR RELATIVE HUMIDITY IN DRYING KINETICS OF KIWI

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In this work, effects of drying air relative humidity to drying kiwi is investigated experimentally for 4 mm and 6 mm thickness and, 60 °C of air temperature, 1.0 m/s of air velocity, and 5%, 10%, 20% of relative humidity. Obtained results from experiments and moisture ratio (MR) values were applied to some selected models from literature and experimental data are compared with results of models. As a result, experimental data were quite compatible with model results. In addition, correlation coefficient ($R^2$) and the root mean square error (RMSE) values are calculated and the lowest error model was determined.

Keywords: Drying, Kiwi, Relative humidity, Drying kinetics.

Introduction

Agricultural products should be kept with special methods until they would be consumed because they cannot be consumed completely as fresh state. Heating (conservation), cooling or freezing, drying and addition of some chemical conservators are some of these methods. Drying is a method that slows enzymes and hence prevents nutrients from decomposition by reducing humidity causing mould, bacteria and ferments in fruits and vegetables. Although this method can be occur in the nature by itself, it cannot be applied at anywhere at any time. Additionally, products are exposing to dust, dirt and environmental effects during drying under sun at open air conditions, drying period is long and quality and economic values of products are degraded. To avoid these negative effects, drying under controlled circumstances with special designed dryers is became indispensable. In this way, quality and clean products with long shelf life can be acquired in shorter periods.

Mathematical Formulation

Moisture content can be defined as a measure of the moisture contained in a matter. Moisture content can be expressed in two ways; percentage wet base and dry base. Respectively, percentage wet base and dry base of moisture content can be calculated as following:

\[
\% N_{wb} = \frac{M_w}{M_w + M_d} \times 100
\]  
\[
N_{db} = \frac{M_w}{M_d}
\]  

The moisture ratio (MR) during drying experiments was calculated using the following equation:

\[
MR = \frac{N_t}{N_0}
\]  

Moisture content change per unit time in dried product is called "drying rate". Drying rate is calculated with the equation below.

\[
DR = \frac{N_t - N_{t,\infty}}{\Delta t}
\]  

<table>
<thead>
<tr>
<th>Model Name</th>
<th>Model</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newton</td>
<td>MR = \exp(-kt)</td>
<td>Ayensu [11]</td>
</tr>
<tr>
<td>Page</td>
<td>MR = \exp(-kt^2)</td>
<td>Diamante and Munro [12]</td>
</tr>
<tr>
<td>Henderson and Pabis</td>
<td>MR = a \exp(-kt) + c</td>
<td>Pal and Chakraverty [14]</td>
</tr>
<tr>
<td>Logarithmic</td>
<td>MR = a \exp(-kt)</td>
<td>Yaldiz and Ertekin [15]</td>
</tr>
<tr>
<td>Two Term</td>
<td>MR = a \exp(-kt_d) + b \exp(-kt_d)</td>
<td>Rahman et al. [16]</td>
</tr>
<tr>
<td>Two Term Exponential</td>
<td>MR = a \exp(-kt) + (1-a) \exp(-kat)</td>
<td>Yaldiz and Ertekin [15]</td>
</tr>
<tr>
<td>Wang and Singh</td>
<td>MR = 1 + at + bt</td>
<td>Wang and Singh [17]</td>
</tr>
<tr>
<td>Approximation of diffusion</td>
<td>MR = a \exp(-kt) + (1-a) \exp(-kbt)</td>
<td>Yaldiz and Ertekin [15]</td>
</tr>
<tr>
<td>Midilli et al.</td>
<td>MR = a \exp(-kbt') + bt</td>
<td>Midilli, Kucuk and Yapar [18]</td>
</tr>
</tbody>
</table>

Due to a very short warm-up phase during drying of agricultural products, drying takes place with constant and declining rates in changing periods. For describing drying, many mathematical models are available in the literature. Table 1 shows some of the drying models in literature.

Experimental Study

In the experiments, kiwi was used which grows in Artvin, Yalova, Adapazari, Rize, Antalya regions in Turkey during the recent years. The kiwi is rich in terms of potassium, fiber and vitamin A, C, E. Also it contains of calcium, iron and magnesium minerals. Figure 1 shows the structure of kiwi.
To determine the drying characteristics of apricot, a convection-type of dryer manufactured in Selçuk University Mechanical Engineering Department. Figure 2 shows the experimental setup of the dryer. The test setup consist of fresh air intake, air conditioning unit, drying cabinet, outlet air and the fresh air mixing unit, automatic control unit and channel connections. The dryer designed for desired constant cabin temperature, air speed and relative humidity.

In the system the measuring elements are placed to measure the drying air temperature, speed and relative humidity values. The measured values were monitored and recorded in the desired time intervals via a programmable logic controller (PLC) and a LCD monitor. Figure 3 shows the measurement areas and measuring elements.

In test setup at point 1 fresh air temperature, speed and relative humidity; point 2 the air velocity of outlet; point 3 temperature and relative humidity of the mixed air; at point 4 temperature of the outlet of the air cooler; at point 5 the air temperature, speed and relative humidity of entrance to cabin; at point 6 the drying air temperature and relative humidity of blown air of the product at the cabin and point 7 the exhaust air temperature and relative humidity were measured.
Before the experiments some typical experiments were done for measurement accuracy of the cabin temperature, speed and relative humidity values. The air temperature, velocity and relative humidity values change over time in these experiments are given respectively in Figures 4, 5 and 6.
In all experiments, blown drying air temperature, velocity and relative humidity was respectively measured ± 0.33 °C, ± 0.26 m/s and ± 0.54 % accurate.

The Experiments

Kiwi were used in the experiments were concealed in the +4 °C refrigerator at least 24 hours after the purchase. Later on, fruits were contained 2 hours under laboratory conditions and thermal balance was provided with environment. For the detection of water (moisture) found in kiwi, infrared Precisa XM 60-style moisture measurement device was used. In the experiments for kiwi the first moisture content was measured as 86.25 %.

To determine the drying characteristics of apricots, 1.0 m/s drying air velocity, %5, %10, %20 relative humidity values, 60 °C temperature values were used. Kiwi were sliced in to 4 mm and 6 mm thick parts. The initial weights of the test samples were measured and experiments were started by putting them to the drying cabinet compartments. Weight measurements were made at every 15 minutes. Cabinet trays were removed quickly and carefully from the cabinet and their weights were measured with a sensitive device. In the meantime, weighing process of each tray was completed in 15 seconds to avoid damage to the product characteristics.

Results and Discussion

To describe to drying kiwi and effects of drying air relative humidity values investigated experimentally for 4 mm and 6 mm thick slices of kiwi at 60 °C of air temperature, 1.0 m/s of air velocity, and 5%, 10%, 20% of relative humidity. Obtained moisture ratio (MR) values from experiments were applied to some models (Newton, Page, Henderson and Pabis, Wangh and Singh, Logaritmic, Midilli) by utilizing Matlab™ software and their correlation coefficient ($R^2$) and the root mean square error (RMSE) values were analyzed. The results obtained for different drying conditions are given in Tables 2 and 3 [19].
Table 2. Coefficients and statistical data (4 mm).

Table 3. Coefficients and statistical data (6 mm).

Under different conditions, various models were utilized to describe drying of kiwi and statistical data ($R^2$ and RMSE) were examined. The experimental data was quite compatible with all model results and the Midilli et al. is the most compatible drying model among all. In Midilli et al. model, the correlation coefficient ($R^2$) ranged from 0.9996 to 0.9999. In addition, in Figures 7 and 8 experimental and model results were compared [19].
Conclusions

Drying behavior of kiwi slices is investigated in a specifically developed convective dryer for three different relative humidity values and two different thickness.

From drying curves, it is realized that drying rate is decreasing through drying period. In different conditions, statistical data ($R^2$ and RMSE) about six selected drying models were examined and results showed that the best model is Midilli et al. to describe the drying of kiwi. In this model, the correlation coefficient ($R^2$) ranged from 0.9996 to 0.9999. This shows that the model results are quite compatible with experimental data.
Nomenclature

\(DR\)  
Drying rate \((g_{w}/g_{dm} \, m)\)

\(M_d\)  
Mass of dry matter (g)

\(M_w\)  
Mass of wet matter (g)

\(M_o\)  
Initial mass (g)

\(MR\)  
Moisture ratio

\(N_o\)  
Initial moisture content \((g_{w}/g_{dm})\)

\(N_t\)  
Moisture content at time \(t\)

\(N_{t+\Delta t}\)  
Moisture content at time \(t+\Delta t\)

\(N_{wb}\)  
Wet base of moisture content

\(N_{db}\)  
Dry base of moisture content

\(R^2\)  
Correlation coefficient

\(RMSE\)  
Root mean square error

\(RH\)  
Relative humidity

\(t\)  
Drying time (minute)

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References


